International Journal of Mathematics and
Computer Applications Research (IJMCAR)
ISSN(P): 2249-6955; ISSN(E): 2249-8060
Vol. 6, Issue 4, Aug 2016, 41-62

HALL CURRENT AND RADIATION EFFECTS ON MHD FREE CONVECTIVE HEAT AND MASS TRANSFER FLOW PAST AN ACCELERATED INCLINED POROUS PLATE WITH THERMAL DIFFUSION

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ABSTRACT

An analysis has been carried out to study the effects of Hall current and radiation of MHD free convective heat and mass transfer flow past an accelerated inclined plate with temperature and concentration in a porous medium in presence of thermal diffusion and heat source TRANSFER. Exact solutions for velocity, temperature and concentration of the flow are obtained by applying Laplace transforms. The influences of different physical parameters on velocity, temperature and species concentration are examined with the help of graphs. Also numerical values of skin friction, Nusselt number and Sherwood number are recorded in tabular form and analyzed.

KEYWORDS: Free Convection Flow, Hall Current, Thermal Radiation, Heat and Mass Transfer, Thermal Diffusion

Received: Jul 12, 2016; **Accepted:** Aug 03, 2016; **Published:** Aug 12, 2016; **Paper Id.:** IJMCARAUG20165

Original Article

1 INTRODUCTION

The flow problems of electrically conducting fluids are currently receiving considerable attention. MHD flows have many practical applications such as electromagnetic flow meters, electromagnetic pumps and hydromagnetic generators etc. The interest in magnetohydrodynamic (MHD) convective flows with heat transfer is renewed due to its importance in the design of MHD based equipments, generators and accelerators in geophysics, in systems like underground water and energy storage. Several scholars have shown their interest in studying MHD and heat transfer flows in porous and non-porous media. In addition, this type of flow finds applications in many engineering problems such as MHD generators, plasma studies, nuclear reactors, MHD pumps, MHD bearing and geothermal energy extractions. Many technological problems as well as natural phenomena are susceptible to MHD heat and mass transfer analysis. Geophysics concepts encounter MHD heat and mass transfer characteristics in the exchanges of conducting fluids and magnetic fields. Engineers and scientists employ many principles of MHD in the drawing of heat exchangers pumps and flow meters, in space vehicle impulsion, thermal guard, braking, power and re-entry, in creating new type of power generating systems etc. In view of technical point, MHD convection and radiation flow problems are very much considerable in the areas of planetary magnetospheres, aeronautics, chemical engineering and electronics. Several studies of the above phenomena of MHD convection have been covered by many researchers. The combined effects of convective heat and mass transfer on the flow of a viscous, incompressible and electrically conducting fluid has many engineering and geophysical applications such as in geothermal reservoirs, drying of porous solids, thermal insulation, and enhanced oil recovery, cooling of nuclear reactor and underground energy transports. Rapits and Singh [1] considered and studied the influences of uniform transverse magnetic field on the natural convection flow of a conducting fluid past an endless vertical plate for the

special classes of impulsive and uniformly accelerated motions. MHD conjugative heat transfer problem from vertical surfaces surrounded in porous media have established by Duwairi and Al-Kablawi [2]. Seddeek [3] examined and analyzed the impact of changeable viscosity and magnetic field on the flow past a continuously affecting porous plate in the presence of heat transfer. Abdelkhalek [4] investigated the effects of mass transfer on steady two-dimensional laminar MHD mixed convection flow. Chowdhury and Islam [5] presented a theoretical analysis of a MHD free convection flow of a viso-elastic fluid near to a vertical porous plate. Singh,P.K.[6] considered and studied Heat and Mass Transfer in MHD Boundary Layer Flow past an Inclined porous Plate with Viscous Dissipation in. Rajesh and Vijaya kumar verma [7] examined and analyzed radiation and mass transfer influences on MHD natural convection flow past an exponentially accelerated perpendicular plate with the consideration of changeable temperature.

Takhar and Ram [8] have considered MHD natural convection flow of water through a porous medium. MHD free convection near a affecting perpendicular plate in the occurrence of thermal radiation is studied by Das and Das [9]. The effects of variable thermal conductivity and heat source/sink on MHD flow near a stagnation point on a linearly stretching sheet are examined by Sharma and Singh [10]. Chen [11] considered and analyzed the problem of combined heat and mass transfer of MHD natural convection near to a upright surface with ohmic heating in conducting field. Recently Reddy et al., [12] studied an unsteady free convective MHD non Newtonian flow over a porous medium bounded by an inclined porous plate. Ravikumar et al., [13-14] studied and investigated the effects of Magnetic field and radiation on a double diffusive free convective flow bounded by two infinite impermeable plates in the occurrence of chemical reaction.

The influence of a uniform transverse magnetic field on the motion of an electrically conducting fluid past a stretching sheet was investigated by Pavlov [15], Chakravarty and Gupta [16], Andersson [17], Andersson et al. [18]. Alam et.al [19] examined and analyzed the combined effect of viscous dissipation and Joule heating on steady and examined MHD natural convective combined heat and mass transfer flow of a viscous incompressible fluid past a semi-infinite inclined radiate isothermal permeable oscillating surface in the presence of thermophoresis.

In most cases, the Hall term was ignored in applies Ohm’s law as it has no marked effect for small and reasonable values of the magnetic field. However, the current movement for the application of MHD is towards a strong magnetic field, so that the influence of electromagnetic force is noticeable [20]. Under these situation, the Hall current is significant and it has a marked effect on the magnitude and direction of the current density and consequently on the magnetic force term. Attia [21] has studied and analyzed the influence of the Hall current on the velocity and temperature fields of an unsteady flow of a conducting Newtonian fluid between two infinite non-conducting horizontal parallel stationary and porous plates.

The aim of the present investigation is to study and analyze the effects of Hall current and radiation of MHD unsteady natural free convection combined heat and mass transfer flow of a viscous, electrically conducting incompressible fluid near an infinite accelerate inclined plate embedded in porous medium which moves with time dependent velocity under the influence of uniform magnetic field, apply normal to the plate. A general exact solution of the governing partial differential equation is obtained by using Laplace transform technique.

2 FORMULATION OF THE PROBLEM

Consider unsteady free convection heat and mass transfer flow of a viscous incompressible and electrically conducting fluid along an infinite non-conducting accelerated inclined plate with an acute angle α through a porous medium. x* direction is taken along the leading edge of the inclined plate and y* is normal to it and extends parallel to x*-axis. A magnetic field of strength B0 is introduced to the normal to the direction to the flow.

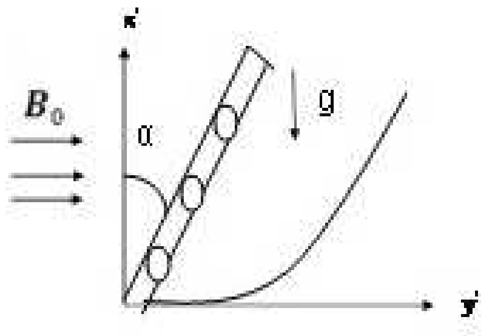

Figure 1: Physical Model and Co-Ordinate System

Initially for time t* ≤ 0, the plate and the fluid are maintained at the same constant temperature T_∞^* in a stationary condition with the same species concentration C_∞^* at all points. Subsequently (t* > 0), the plate is assumed to be accelerating with a velocity $U_0 f(t^*)$ in its own plane along the x*-axis, instantaneously the temperature of the plate and the concentration are raised to T_w^* and C_w^* respectively, which are hereafter regarded as constant. The flow of the fluid is assumed to be in the direction of the x*-axis, so the physical quantities are functions of the space co-ordinate y* and time t* only. Taking into consideration the assumption made above, in accordance with the usual Boussinesq approximation, the governing equations for unsteady free convective boundary layer flow of viscous incompressible and electrical conducting fluid along infinite accelerated inclined plate through a porous medium with hall current, radiation and thermal diffusion in two dimensional flow can be expressed as :

Momentum Equation

$$\frac{\partial u^*}{\partial t^*} = \vartheta \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta^*(T^* - T_\infty^*)\cos\alpha + g\beta^*(C^* - C_\infty^*)\cos\alpha - \frac{\vartheta}{K^*}u^* - \frac{\sigma B_0^2}{\rho(1+m^2)}u^* \qquad (1)$$

Energy Equation

$$\frac{\partial T^*}{\partial t^*} = \frac{K^*}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial y^*} - Q^*(T^* - T_\infty{}^*) \qquad (2)$$

Concentration Equation

$$\frac{\partial C^*}{\partial t^*} = D_M \frac{\partial^2 C^*}{\partial y^{*2}} - D_T \frac{\partial^2 T^*}{\partial y^{*2}} \qquad (3)$$

where u^* velocity, T^* is the temperature, C^* is the species concentration and g is the acceleration due to gravity.

The initial and boundary conditions corresponding to the present problem are

$$u^*(y^*, t^*) = 0, T^*(y^*, t^*) = T_\infty^*, C^*(y^*, t^*) = C_\infty^* \; for\; y^* \geq 0 \; and \; t^* \leq 0$$

$u^*(0,t^*) = u_0 e^{a_0{}^* t^*}\ T^*(0,t^*) = T_w^*\ , C^*(0,t^*) = C_w^*\ for\ t^* \leq 0)\ u^* \to 0, T^* \to T_\infty^*\ , C^* \to C_\infty^*\ y \quad * \quad \to \quad \infty$ $and\ for\ t^* > 0$ (4)

The radiative heat flux q_r^* is given by

$$\frac{\partial q_r^*}{\partial y^*} = 4(T^* - T_\infty^*)I^* \tag{5}$$

Where $I^* = \int_0^\infty K_{\lambda w} \frac{\partial e_{b\lambda}}{\partial T^*}\, d\lambda$, $K_{w\lambda}$ is absorption coefficient and $e_{b\lambda}$ is Plank function.

To convert the above governing equations into non-dimensional form, the following parameters are introduced:

$$u_0 = \frac{u_0^*}{U_0}\ , y = \frac{y^* U_0}{\vartheta}, t = \frac{t^* U_0^2}{\vartheta}\ , G_r = \frac{\vartheta g \beta_T (T_W^* - T_\infty^*)}{U_0^3}\ , M = \frac{\sigma B_0^2 \vartheta}{\rho U_0^2}, P_r = \frac{\rho \vartheta C_p}{k},$$

$$G_m = \frac{\vartheta g \beta_C (C_W^* - C_\infty^*)}{U_0^3}\ , S_c = \frac{\vartheta}{D_M}\ , S_0 = \frac{(T_W^* - T_\infty^*) D_t}{(C_W^* - C_\infty^*)\vartheta}, k = \frac{k^* U_0^2}{\vartheta^2}\ , \gamma = \frac{k_1^* \vartheta}{U_0^2},$$

$$S_c = \frac{\vartheta}{D^*}, \omega = \frac{\omega^* \vartheta}{U_0^2}, Q = \frac{Q^* \vartheta^2}{k * U_0^2}\ , \theta = \frac{(T^* - T_\infty^*)}{T_W^* - T_\infty^*}$$

$$C = \frac{(C^* - C_\infty^*)}{C_W^* - C_\infty^*}, F = \frac{4\vartheta I^*}{\rho C_p U_0^2}, a_o = \frac{a_0^* \vartheta}{U_0^2} \tag{6}$$

where Gr is the thermal Grashof number, Gm is the mass Grashof number, k is the permeability parameter, M is the magnetic parameter, m is the hall current parameter, Pr is Prandtl number, Sc is Schmidt number, β_T is thermal expansion coefficient, β_C is concentration expansion coefficient and a_o* is dimensional accelerating parameter and other physical variables have their usual meanings.

With the help of (6), the governing equations (1) to (3) reduce to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + G_r(cos\alpha)\theta + G_m(cos\alpha)C - Nu \tag{7}$$

$$\frac{\partial^2 \theta}{\partial y^2} - P_r \frac{\partial \theta}{\partial t} + (F + Q)\theta = 0 \tag{8}$$

$$\frac{\partial^2 C}{\partial y^2} - S_c \frac{\partial C}{\partial t} + S_c S_0 \frac{\partial^2 \theta}{\partial y^2} = 0 \tag{9}$$

Where $M_1 = \frac{M}{1+m^2}\ , N = (\frac{1}{K} + M_1)$

The corresponding initial and boundary conditions in non-dimensional form are:

$u(y,t) = 0, \theta(y,t) = 0, C(y,t) = 0\ for\ y^* \geq 0\ and\ t^* \leq 0$

$u(0,t) = e^{a_0 t}, \theta(0,t) = 1, C(0,t) = 1\ for\ t^* > 0)$

$$u \to 0, \theta \to 0, C \to 0\ y \to \infty\ and\ for\ t > 0 \tag{10}$$

3 SOLUTION OF THE PROBLEM

In order to obtain the analytical solutions of the system of differential equations (7) to (9), we shall use the Laplace transform technique.

Applying the Laplace transform (with respect to time t) to equations (7) to (9) and boundary conditions (10), we

get

$$\bar{\theta} = \frac{1}{s}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right) \quad (11)$$

$$\bar{C} = \frac{1}{s}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) - m_2\frac{1}{s+m_3}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) - m_6\frac{1}{s}\exp\left(-y\sqrt{S_c}\sqrt{s}\right)$$

$$+\frac{m_6}{s+m_5}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) + m_2\frac{1}{s+m_3}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right)$$

$$+m_6\frac{1}{s}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right) - \frac{m_6}{s+m_5}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right) \text{ for } P_r \neq 1 \text{ and } S_c \neq 1 \quad (12)$$

$$\bar{u}(y,s) = \bar{f}(s)\exp\left(-y\sqrt{s+N}\right) + \frac{m_{29}}{s}\exp\left(-y\sqrt{s+N}\right) + \frac{m_{10}}{s+m_9}\exp\left(-y\sqrt{s+N}\right)$$

$$+\frac{m_{30}}{s-m_{12}}\exp\left(-y\sqrt{s+N}\right) + \frac{m_{31}}{s+m_3}\exp\left(-y\sqrt{s+N}\right) + \frac{m_{32}}{s+m_5}\exp\left(-y\sqrt{s+N}\right)$$

$$+\frac{m_{33}}{s+m_{21}}\exp\left(-y\sqrt{s+N}\right) + \frac{m_{34}}{s}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right)$$

$$-\frac{m_{10}}{s+m_9}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right)$$

$$-m_{13}\frac{1}{s}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) + \frac{m_{35}}{s-m_{12}}\exp\left(-y\sqrt{S_c}\sqrt{s}\right)$$

$$\frac{m_{15}}{s+m_3}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) + \frac{m_{18}}{s-m_{12}}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) + \frac{m_{36}}{s+m_{21}}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right)$$

$$+\frac{m_{19}}{s+m_5}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) + \frac{m_{23}}{s+m_3}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right)$$

$$+\frac{m_{28}}{s+m_5}\exp\left(-y\sqrt{P_r}\sqrt{s+S_1}\right) \text{ for } P_r \neq 1 \text{ and } S_c \neq 1 \quad (13)$$

For $P_r = 1$ and $S_c = 1$

$$\bar{\theta} = \frac{1}{s}\exp\left(-y\sqrt{s+S_1}\right) \quad (14)$$

$$\bar{C} = \frac{1}{s}\exp\left(-y\sqrt{s}\right) - B_1\frac{1}{s}\exp\left(-y\sqrt{s}\right) + \frac{S_0}{s}\exp\left(-y\sqrt{s}\right)$$

$$+B_1\frac{1}{s}\exp\left(-y\sqrt{s+S_1}\right) - \frac{S_0}{s}\exp\left(-y\sqrt{s+F}\right) \quad (15)$$

$$\bar{u}(y,s) = \bar{f}(s)\exp\left(-y\sqrt{s+N}\right) - B_9\frac{1}{s}\exp\left(-y\sqrt{s+N}\right) + B_8\exp\left(-y\sqrt{s+N}\right)$$

$$+B_6\frac{1}{s}\exp\left(-y\sqrt{s+S_1}\right) + B_7\frac{1}{s}\exp\left(-y\sqrt{s}\right) - B_8\exp\left(-y\sqrt{s}\right) \quad (16)$$

Then, inverting equations (11) to (16) in the usual way we get the general solution of the problem for the temperature $\theta(y,t)$, the species concentration C(y, t) and velocity u(y, t) for t > 0 in the non dimensional form as

$$\theta = \frac{1}{2}\left[e^{-y\sqrt{P_r m_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}} - \sqrt{m_1 t}\right) + e^{y\sqrt{P_r m_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}} + \sqrt{m_1 t}\right)\right] \text{ for } P_r \neq 1 \quad (17)$$

$$C = erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}\right) - m_2\{\frac{e^{-m_3 t}}{2}[e^{-y\sqrt{S_c}\sqrt{-m_3}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}} - \sqrt{-m_3 t}\right)$$

$$+e^{y\sqrt{S_c}\sqrt{-m_3}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}} + \sqrt{-m_3 t}\right)]\} - m_6 erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}\right)$$

$$+m_6\left\{\frac{e^{-m_5t}}{2}\left[e^{-y\sqrt{S_c}\sqrt{-m_5}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}-\sqrt{-m_5t}\right)+\right.\right.$$

$$\left.\left.e^{y\sqrt{S_c}\sqrt{-m_5}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}+\sqrt{-m_5t}\right)\right]\right\}+m_2\{\frac{e^{-m_3t}}{2}[e^{-y\sqrt{P_r}\sqrt{-m_3+m_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-m_3+m_1)t}\right)]$$

$$+e^{y\sqrt{P_r}\sqrt{-m_3+m_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-m_3+m_1)t}\right)\}$$

$$+m_6\{\frac{1}{2}\left[e^{-y\sqrt{P_r}\sqrt{m_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-(\sqrt{m_1t})\right)+e^{y\sqrt{P_r}\sqrt{m_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+(\sqrt{m_1t})\right)\right]\}$$

$$-m_6\{\frac{e^{-m_5t}}{2}[e^{-y\sqrt{P_r}\sqrt{-m_5+m_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-m_5+m_1)t}\right)$$

$$+e^{y\sqrt{P_r}\sqrt{-m_5+m_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-m_5+m_1)t}\right)]\}\text{ for } P_r\neq 1 \text{ and for } S_c\neq 1 \tag{18}$$

$$\theta=\frac{1}{2}[\exp(-y\sqrt{S_1})erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{S_1t}\right)+\exp(y\sqrt{S_1})erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{S_1t}\right)]\text{ for } P_r=1 \tag{19}$$

$$C=B_1\frac{y}{2\sqrt{\pi t^3}}\exp\left(\frac{-y^2}{4t}-S_1t\right)-B_1\frac{y}{2\sqrt{\pi t^3}}\exp\left(\frac{-y^2}{4t}\right)+B_2erfc\left(\frac{y}{2\sqrt{t}}\right)$$

$$-\frac{s_0}{2}[\exp(-y\sqrt{S_1})erfc(\frac{y}{2\sqrt{t}}-\sqrt{S_1t})+\exp(y\sqrt{S_1})\,\mathrm{erfc}\left(\frac{y}{2\sqrt{t}}+\sqrt{S_1t}\right)]$$

for $P_r = 1$ and $S_c = 1$ (20)

Thus the expressions (17) to (20) are the general solution of the present problem. These general solutions include the effects of heating, the diffusion and the motion of the plate. Since the non dimensional temperature $\theta(y,t)$, non dimensional species concentration C(y, t) is clearly described in (17) to (20), so we shall confine ourselves to non dimensional velocity u(y,t) for exponentially accelerated inclined plate.

For an exponentially accelerated inclined plate f(t) = exp(a_ot), where a_o is dimensionless accelerating parameter.

Then $\bar{f}(s)=\frac{1}{s-a_0}$

In this case we observe that the results (17) to (20) for $\theta(y,t)$, and C(y, t) are unaffected and the expression for u(y,t) is reduced to

$$u(y,t)=\frac{e^{a_0t}}{2}\left[e^{-y\sqrt{a_0+N}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(a_0+N)t}\right)+e^{y\sqrt{a_0+N}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(a_0+N)t}\right)\right]+\emptyset(y,t) \tag{21}$$

Where

$$\emptyset(y,t)=\frac{m_{29}}{2}\left[e^{-y\sqrt{N}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{Nt}\right)+e^{y\sqrt{N}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{Nt}\right)\right]$$

$$+m_{10}\frac{e^{-m_9t}}{2}[e^{-y\sqrt{-m_9+N}}\, erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(-m_9+N)t}\right)+e^{y\sqrt{-m_9+N}}\, erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(-m_9+N)t}\right)]$$

$$+m_{30}\frac{e^{m_{12}t}}{2}[e^{-y\sqrt{m_{12}+N}}\, erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(m_{12}+N)t}\right)+e^{y\sqrt{m_{12}+N}}\, erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(m_{12}+N)t}\right)]$$

$$+m_{31}\frac{e^{-m_3t}}{2}[e^{-y\sqrt{-m_3+N}}\, erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(-m_3+N)t}\right)+e^{y\sqrt{-m_3+N}}\, erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(-m_3+N)t}\right)]$$

$$+m_{32}\frac{e^{-m_5 t}}{2}[e^{-y\sqrt{-m_5+N}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(-m_5+N)t}\right)+e^{y\sqrt{-m_5+N}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(-m_5+N)t}\right)]+$$

$$m_{33}\frac{e^{-m_{21}t}}{2}\left[e^{-y\sqrt{-m_{21}+N}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(-m_{21}+N)t}\right)+e^{y\sqrt{-m_{21}+N}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(-m_{21}+N)t}\right)\right]$$

$$+\frac{m_{34}}{2}\left[e^{-y\sqrt{P_r}\sqrt{m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-(\sqrt{m_1 t})\right)+e^{y\sqrt{P_r}\sqrt{m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+(\sqrt{m_1 t})\right)\right]-$$

$$m_{10}\{\frac{e^{-m_9 t}}{2}[e^{-y\sqrt{P_r}\sqrt{-m_9+m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-m_9+m_1)t}\right)+$$

$$e^{y\sqrt{P_r}\sqrt{-m_9+m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-m_9+m_1)t}\right)]\}-m_{13}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}\right)+m_{15}\left\{\frac{e^{-m_3 t}}{2}\left[e^{-y\sqrt{-S_c}\sqrt{m_3}}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}-\sqrt{-m_3 t}\right)+\right.\right.$$

$$\left.\left.e^{y\sqrt{-S_c}\sqrt{m_3}}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}+\sqrt{-m_3 t}\right)\right]\right\}$$

$$+m_{18}\{\frac{e^{m_{12}t}}{2}[e^{-y\sqrt{S_c}\sqrt{m_{12}}}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}-\sqrt{m_{12}t}\right)+e^{y\sqrt{S_c}\sqrt{m_{12}}}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}+\sqrt{m_{12}t}\right)]\}$$

$$+m_{19}\{\frac{e^{-m_5 t}}{2}[e^{-y\sqrt{S_c}\sqrt{m_5}}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}-\sqrt{-m_5 t}\right)+$$

$$e^{y\sqrt{-S_c}\sqrt{m_5}}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}+\sqrt{-m_5 t}\right)]\}+m_{35}\{\frac{e^{m_{12}t}}{2}[e^{-y\sqrt{S_c}\sqrt{m_{12}}}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}-\sqrt{m_{12}t}\right)+e^{y\sqrt{S_c}\sqrt{m_{12}}}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}+\right.$$

$$\left.\sqrt{m_{12}t}\right)]\}+m_{36}\{\frac{e^{-m_{21}t}}{2}[e^{-y\sqrt{P_r}\sqrt{-m_{21}+m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-m_{21}+m_1)t}\right)+$$

$$e^{y\sqrt{P_r}\sqrt{-m_{21}+m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-m_{21}+m_1)t}\right)]\}+m_{23}\{\frac{e^{-m_3 t}}{2}[e^{-y\sqrt{P_r}\sqrt{-m_3+m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-m_3+m_1)t}\right)+$$

$$e^{y\sqrt{P_r}\sqrt{-m_3+m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-m_3+m_1)t}\right)]\}+m_{28}\{\frac{e^{-m_5 t}}{2}[e^{-y\sqrt{P_r}\sqrt{-m_5+m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-m_5+m_1)t}\right)+$$

$$e^{y\sqrt{P_r}\sqrt{-m_5+m_1}}erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-m_5+m_1)t}\right)]\}\ \text{for}\ P_r\neq 1, S_c\neq 1 \tag{22}$$

for $P_r \neq 1$, $S_c \neq 1$ (22)

$$\emptyset(y,t)=B_9\frac{1}{2}[\exp(-y\sqrt{N})erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{Nt}\right)+\exp(y\sqrt{N})erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{Nt}\right)$$

$$+B_8\frac{y}{2\sqrt{\pi t^3}}\exp\left(\frac{-y^2}{4t}-Nt\right)-B_8\frac{y}{2\sqrt{\pi t^3}}\exp\left(\frac{-y^2}{4t}\right)+B_7 erfc\left(\frac{y}{2\sqrt{t}}\right)$$

$$+B_6\frac{1}{2}[\exp(-y\sqrt{S_1})erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{S_1 t}\right)+\exp(y\sqrt{S_1})erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{S_1 t}\right)]$$

for $P_r = 1$ and $S_c = 1$ (23)

Skin-Friction

The quantities of physical interest are the skin-friction due to velocity is given by

$$\boldsymbol{\tau}=\left(\frac{\partial u}{\partial y}\right)_{y=0}=\frac{1}{2}\left[\frac{-2}{\sqrt{\pi t}}\exp(-(a_0+N)t)+\sqrt{a_0+N}\left[erfc(\sqrt{(a_0+N)t})-erfc(-\sqrt{(a_0+N)t})\right]\right]+\left(\frac{\partial\emptyset}{\partial y}\right)_{y=0} \tag{24}$$

Where

$$\left(\frac{\partial \emptyset}{\partial y}\right)_{y=0} =$$

$$\frac{m_{29}}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-Nt}+\sqrt{N}\ \left(erfc(\sqrt{Nt})-erfc(-\sqrt{Nt})\right)\right]+\frac{m_{10}}{2}e^{-m_9 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N-m_9)t}+\sqrt{(N-m_9)}\ \left(erfc(\sqrt{(N-m_9)t})-erfc(-\sqrt{(N-m_9)t})\right)\right]+$$

$$\frac{m_{30}}{2}e^{-m_{12}t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N+m_{12})t}+\sqrt{(N+m_{12})}\ \left(erfc\left(\sqrt{(N+m_{12})t}\right)-erfc\left(-\sqrt{(N+m_{12})t}\right)\right)\right]$$

$$+\frac{m_{31}}{2}e^{-m_3 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N-m_3)t}+\sqrt{(N-m_3)}\ \left(erfc(\sqrt{(N-m_3)t})-erfc(-\sqrt{(N-m_3)t})\right)\right]$$

$$+\frac{m_{32}}{2}e^{-m_5 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N-m_5)t}+\sqrt{(N-m_5)}\ \left(erfc(\sqrt{(N-m_5)t})-erfc(-\sqrt{(N-m_5)t})\right)\right]+$$

$$\frac{m_{33}}{2}e^{-m_{21}t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N-m_{21})t}+\sqrt{(N-m_{21})}\ \left(erfc\left(\sqrt{(N-m_{21})t}\right)-erfc\left(-\sqrt{(N-m_{21})t}\right)\right)\right]+\frac{m_{34}}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-m_1 t}+\right.$$

$$\left.\sqrt{(P_r m_1)}\ \left(erfc(\sqrt{m_1 t})-erfc(-\sqrt{m_1 t})\right)\right]+\frac{m_{10}}{2}e^{-m_9 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(m_1-m_9)t}+\sqrt{(m_1-m_9)P_r}\ \left(erfc(\sqrt{(m_1-m_9)t})-\right.\right.$$

$$\left.\left.erfc(-\sqrt{(m_1-m_9)t})\right)\right]+m_{13}\left[\frac{\sqrt{S_c}}{\sqrt{\pi t}}\right]+\frac{m_{35}}{2}e^{-m_{12}t}\left[\frac{-2\sqrt{S_c}}{\sqrt{\pi t}}e^{-m_{12}t}+\sqrt{(S_c m_{12})}\ \left(erfc(\sqrt{m_{12}t})-erfc(-\sqrt{m_{12}t})\right)\right]+$$

$$\frac{m_{15}}{2}e^{-m_3 t}\left[\frac{-2\sqrt{S_c}}{\sqrt{\pi t}}e^{m_3 t}+\sqrt{(-m_3 S_c)}\ \left(erfc(\sqrt{-m_3 t})-erfc(-\sqrt{-m_3 t})\right)\right]$$

$$+\frac{m_{18}}{2}e^{m_{12}t}\left[\frac{-2\sqrt{S_c}}{\sqrt{\pi t}}e^{-m_{12}t}+\sqrt{(m_{12}S_c)}\ \left(erfc(\sqrt{m_{12}t})-erfc(-\sqrt{m_{12}t})\right)\right]+$$

$$\frac{m_{19}}{2}e^{-m_5 t}\left[\frac{-2\sqrt{S_c}}{\sqrt{\pi t}}e^{m_5 t}+\sqrt{(-m_5 S_c)}\ \left(erfc(\sqrt{(-m_5)t})-erfc(-\sqrt{(-m_5)t})\right)\right]+\frac{m_{36}}{2}e^{-m_{21}t}\left[\frac{-2P_r}{\sqrt{\pi t}}e^{-(m_1-m_{25})t}+\right.$$

$$\left.\sqrt{(m_1-m_{25})P_r}\ \left(erfc(\sqrt{(m_1-m_{25})t})-erfc(-\sqrt{(m_1-m_{25})t})\right)\right]+$$

$$\frac{m_{23}}{2}e^{-m_3 t}\left[\frac{-2P_r}{\sqrt{\pi t}}e^{-(m_1-m_3)t}+\sqrt{(m_1-m_3)P_r}\ \left(erfc(\sqrt{(m_1-m_3)t})-erfc(-\sqrt{(m_1-m_3)t})\right)\right]+$$

$$\frac{m_{28}}{2}e^{-m_5 t}\left[\frac{-2P_r}{\sqrt{\pi t}}e^{-(m_1-m_5)t}+\sqrt{(m_1-m_5)P_r}\ \left(erfc(\sqrt{(m_1-m_5)t})-erfc(-\sqrt{(m_1-m_5)t})\right)\right]\text{ for } P_r \neq 1, S_c \neq 1 \tag{25}$$

$$\left(\frac{\partial \emptyset}{\partial y}\right)_{y=0} = \frac{B_9}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-Nt}+\sqrt{N}\ \left(erfc(\sqrt{Nt})-erfc(-\sqrt{Nt})\right)\right]+\frac{B_8}{2\sqrt{\pi t^3}}e^{-Nt}-\frac{B_8}{2\sqrt{\pi t^3}}-\frac{B_7}{\sqrt{\pi t}}-\frac{B_6}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-S_1 t}+\right.$$

$$\left.\sqrt{S_1}\ \left(erfc(\sqrt{S_1 t})-erfc(-\sqrt{S_1 t})\right)\right]\text{ for } P_r = 1 \text{ and } S_c = 1 \tag{26}$$

Nusselt Number

An interesting phenomenon in this analysis is to examine the effects of t, P_r on the Nusselt number. In non dimensional form, the rate of heat transfer is given by

$$N_u = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \frac{1}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-m_1 t}+\sqrt{(P_r m_1)}\ \left(erfc(\sqrt{m_1 t})-erfc(-\sqrt{m_1 t})\right)\right]\text{ for } P_r \neq 1 \tag{27}$$

$$= \frac{1}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-m_1 t}+\sqrt{(m_1)}\ \left(erfc(\sqrt{m_1 t})-erfc(-\sqrt{m_1 t})\right)\right]\text{ for } P_r = 1 \tag{28}$$

Sherwood Number

Another important physical quantities of interest is the Sherwood number which in non-dimensional form is

$$S_h = -\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

$$= -\sqrt{\frac{S_c}{\pi t}}-\frac{m_2}{2}e^{m_3 t}\left[\frac{-2}{\sqrt{\pi t}}e^{m_3 t}+\sqrt{(-m_3 S_c)}\ \left(erfc\left(\sqrt{-m_3 t}\right)-erfc\left(-\sqrt{-m_3 t}\right)\right)\right]$$

$$+m_6\left[\frac{\sqrt{S_c}}{\sqrt{\pi t}}\right]-\frac{m_6}{2}e^{-m_5 t}\left[\frac{-2}{\sqrt{\pi t}}e^{m_3 t}+\sqrt{(-m_5 S_c)}\ \left(erfc(\sqrt{-m_5 t})-erfc(-\sqrt{-m_5 t})\right)\right]+\frac{m_2}{2}e^{-m_3 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(m_1-m_3)t}+\sqrt{(m_1-m_3)Sc}\ \left(erfc(\sqrt{(m_1-m_3)t})-erfc(-\sqrt{(m_1-m_3)t})\right)\right]+\frac{m_6}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-m_1 t}+\sqrt{(P_r m_1)}\ \left(erfc(\sqrt{m_1 t})-erfc(-\sqrt{m_1 t})\right)\right]-\frac{m_6}{2}e^{-m_5 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(m_1-m_5)t}+\sqrt{(m_1-m_5)P_r}\ \left(erfc(\sqrt{(m_1-m_5)t})-erfc(-\sqrt{(m_1-m_5)t})\right)\right]$$

for $P_r \neq 1$, $S_c \neq 1$ (29)

$$=-\{\frac{B_1}{2\sqrt{\pi t^3}}e^{-S_1 t}-\frac{B_1}{2\sqrt{\pi t^3}}-\frac{B_2}{\sqrt{\pi t}}$$

$$-(-\frac{S_0}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-S_1 t}+\sqrt{S_1}\ \left(erfc(\sqrt{S_1 t})-erfc(-\sqrt{S_1 t})\right))\right]\}\ \text{for } P_r=1 \text{ and } S_c=1$$

(30)

4 RESULTS AND DISCUSSIONS

The system of transformed differential equations (7) - (9) subject to the boundary conditions (10) is solved using Laplace transform technique. To understand the physical meaning of the problem, we have computed the expression for velocity (u), temperature profile (θ), Concentration (C), Skin friction (τ), rate of heat transfer in the form of Nusselt Number and rate of mass transfer in the form of Sherwood number for different values of Prandtl number Pr, magnetic field parameter M, hall current parameter (m), Grashof number (Gr), modified Grashof number (Gm), Schmidt number (Sc), permeability parameter (k), Soret number (S_0), radiation parameter(F), Heat source parameter (Q), and inclination angle α .

The consequences of relevant parameters on the flow field are broken down and discuss with the help of graphs of the velocity profiles, temperature profiles, concentration profiles and tables of Skin-friction coefficient, Nusselt number and Sherwood number.

The velocity profiles for different values of physical parameters (Pr≠1 & Sc≠1) are presented in figures 2-11. From this it is observed that velocity increases as Pr, F, So, M, Gr, Gm, and Q increase respectively, while the velocity decreases as Sc, α and m increase.

Figures 12 - 17 shows the velocity profile (Pr=1 & Sc=1) for different values of magnetic field parameter M, Grashof number Gr, modified Grashof number Gm, radiation parameter F, inclination angle α and hall current parameter m. It is noticed that the velocity increases with increase in F, Gr, Gm, and m respectively, while the velocity decreases as M and α increase.

The temperature profile (Pr ≠ 1) for different values of Prandtl number Pr and radiation parameter F are shown in figure 18 & figure 19. It is observed Pr & F increase as temperature decreases.

Figure 20 shows the temperature profile (Pr = 1) for different values of Heat source parameter Q. It is observed that the temperature decreases with the increase of Q.

Figures 21 - 24 depict the variation of Concentration filed C (Pr≠1 & Sc≠1) against Schmidt number Sc, Soret number S_0, radiation parameter F, Heat source parameter Q . It is noticed that the concentration increases with increase in F and So respectively, while the concentration decreases as Sc and Q increase.

The concentration profile (Pr = 1 & Sc= 1) for different values of Soret number S_0 shown in figure 25. It is observed that concentration increases with the increase of S_0.

Table (1) displays that enhancing Prandtl number Pr, radiation parameter (F), Soret number $S_{0,}$ Grashof number Gr, Grashof number Gm, Source parameter (Q), Hall current parameter (m) results an increasing Skin-friction coefficient. While it decreases with increase of Schmidt number Sc, magnetic field parameter M, Heat inclination angle α ($Pr \neq 1$ & $Sc\neq1$).

Table 2 shows that rising radiation parameter (F), Soret number $S_{0,}$ magnetic field parameter M, Grashof number Gr, modified Grashof number Gm results an increasing Skin-friction coefficient. While it decreases with increase of Heat source parameter (Q), inclination angle α, Hall current parameter (m) (Pr =1 & Sc= 1).

Tables 3 & 4 show the effects of Prandtl number Pr, radiation parameter F, Heat source parameter Q on rate of heat transfer (Nu). It is noticed that the rate of heat transfer increases with the increase of Pr, F and Q.

Table 5 exhibits that increasing Prandtl number Pr, Soret number $S_{0,}$ radiation parameter F, Heat source parameter Q, the rate of mass transfer (Sh) increases. Enhancing Schmidt number Sc, the Sherwood number decreases.

The effects of Soret number $S_{0,}$ radiation parameter F, Heat source parameter Q on rate of mass transfer are shown numerically in Table 6 (Pr = 1 & Sc= 1). It is observed that the rate of mass transfer increases with the increase in So, F and Q.

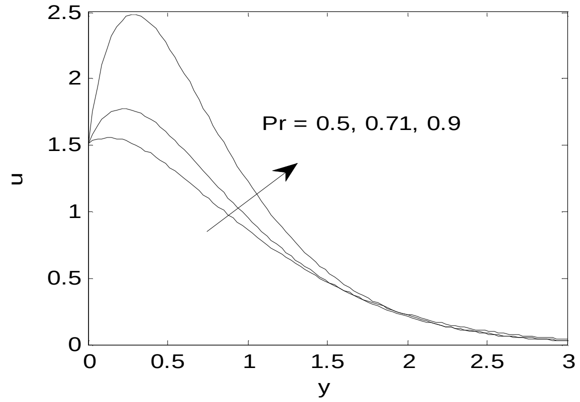

Figure 2: Velocity Distribution for Various Values of Pr

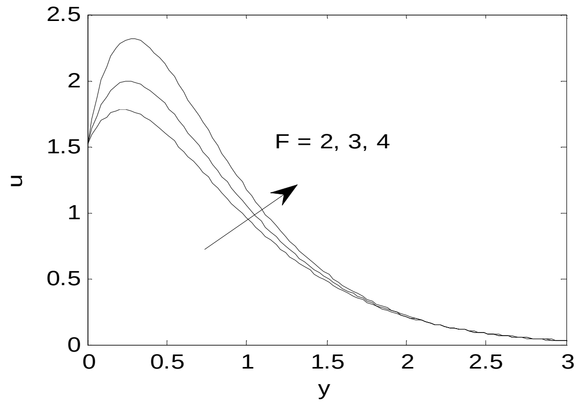

Figure 3: Velocity Distribution for Various Values of F

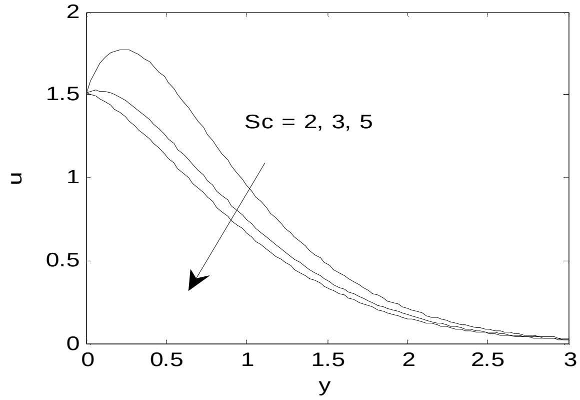

Figure 4: Velocity Distribution for Various Values of Sc

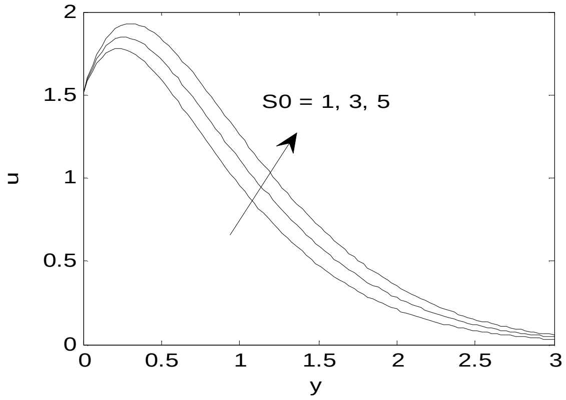

Figure 5: Velocity Distribution for Various Values of So

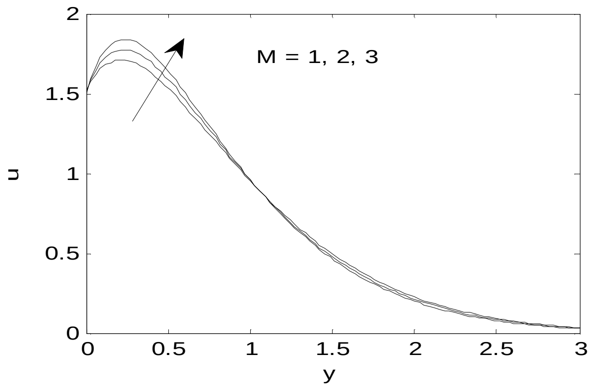

Figure 6: Velocity Distribution for Various Values of M

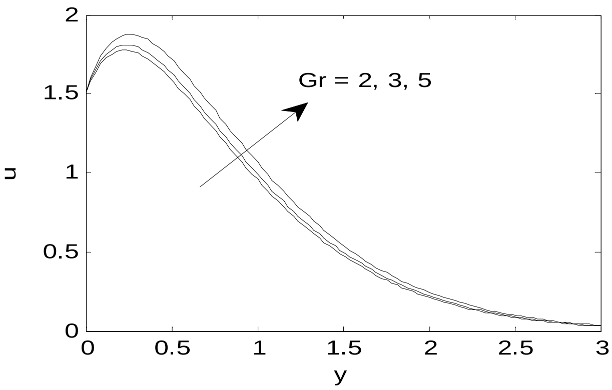

Figure 7: Velocity Distribution for Various values of Gr

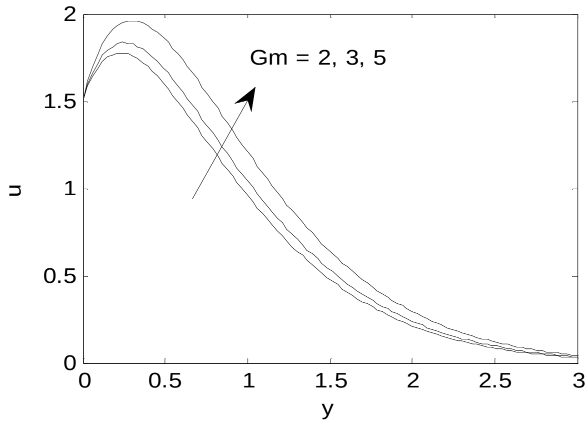

Figure 8: Velocity Distribution for Various Values of Gm

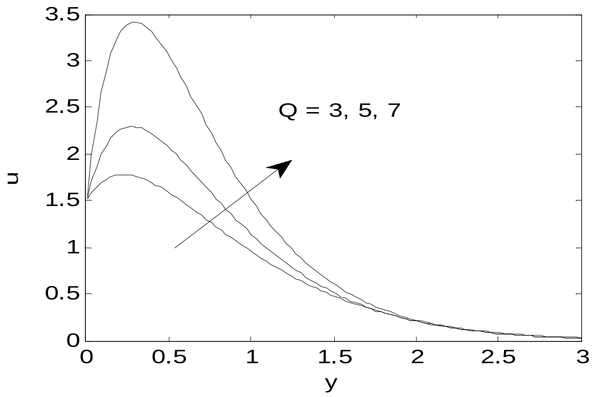

Figure 9: Velocity Distribution for Various Values of Q

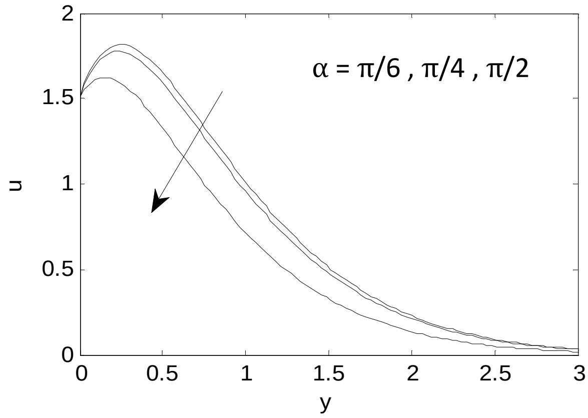

Figure 10: Velocity Distribution for Various Values of Alpha

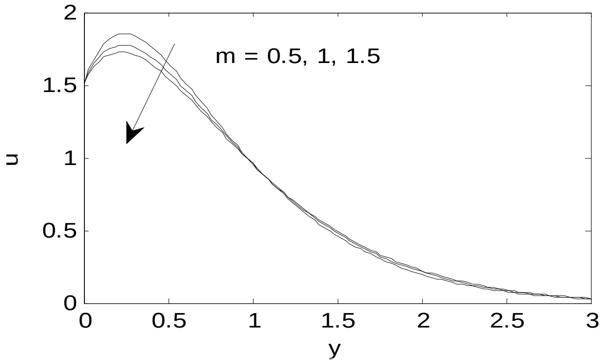

Figure 11: Velocity Distribution for Various Values of m

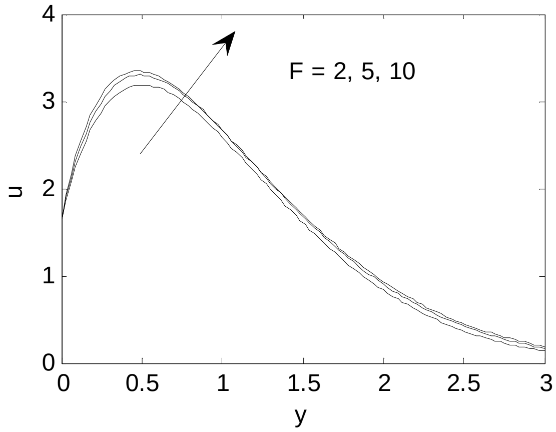

Figure 12: Velocity Distribution for Various Values of F (Pr=1, Sc=1)

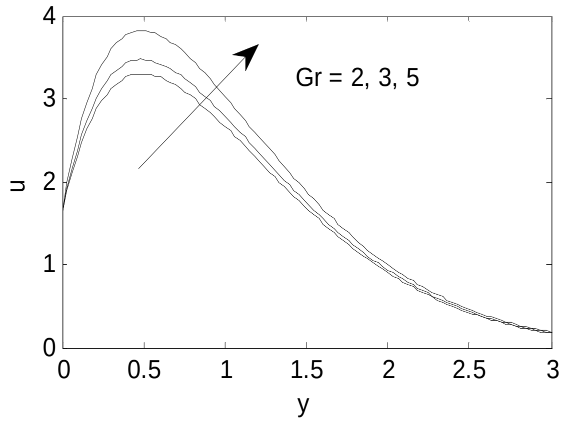

Figure 13: Velocity Distribution for Various Values of Gr (Pr=1, Sc=1)

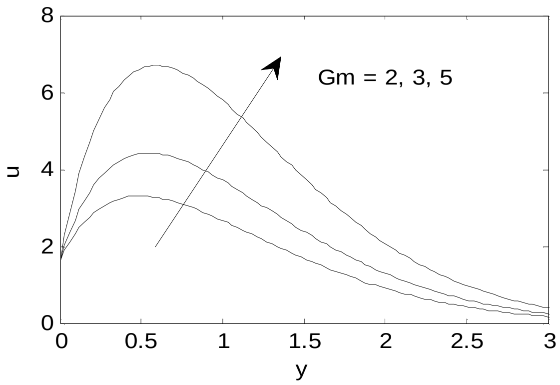

Figure 14: Velocity Distribution for Various Values of Gm

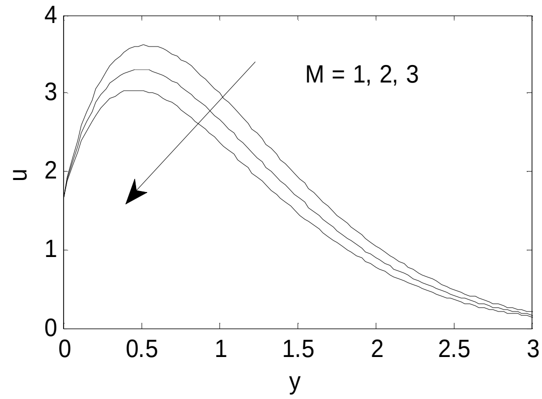

Figure 15: Velocity Distribution for Various Values of M (Pr=1, Sc=1)

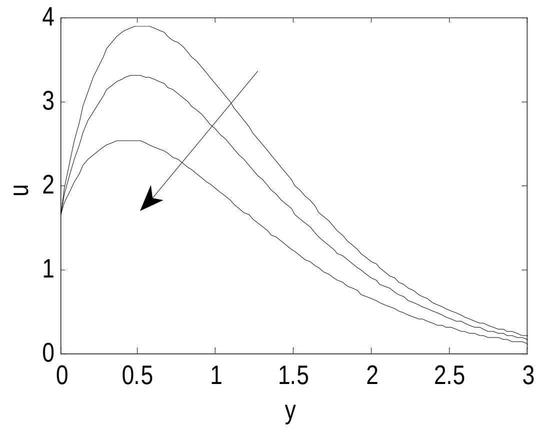

Figure 16: Velocity Distribution for Various Values of Alpha (Pr=1, Sc=1)

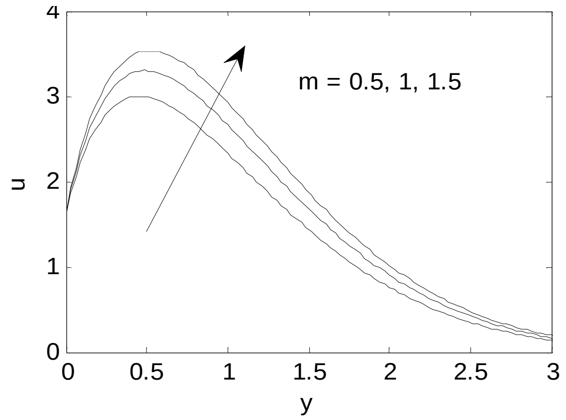

Figure 17: Velocity Distribution for Various Values of m (pr=1, Sc=1)

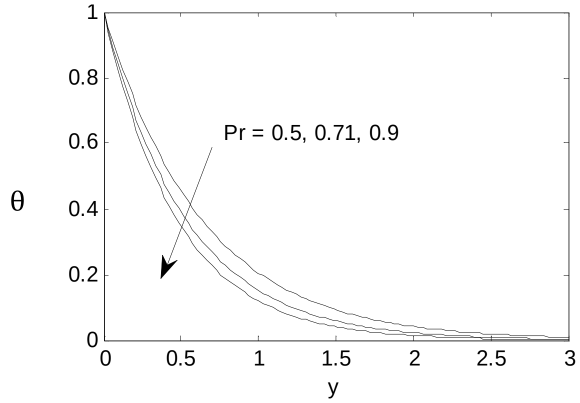

Figure 18: Temperature Distribution for Various Values of Pr

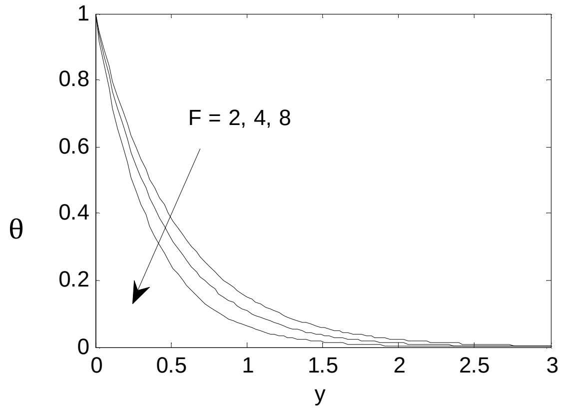

Figure 19: Temperature Distribution for Various Values of F

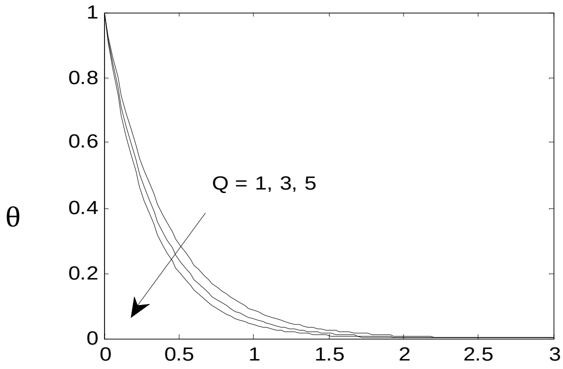

Figure 20: Temperature Distribution for Various Values of Q

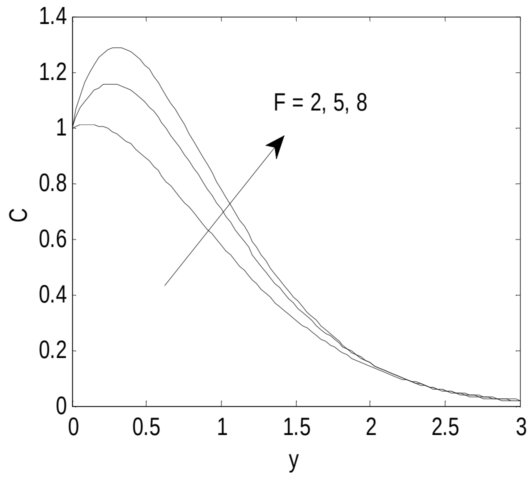

Figure 21: Concentration Distribution for Various Values of F

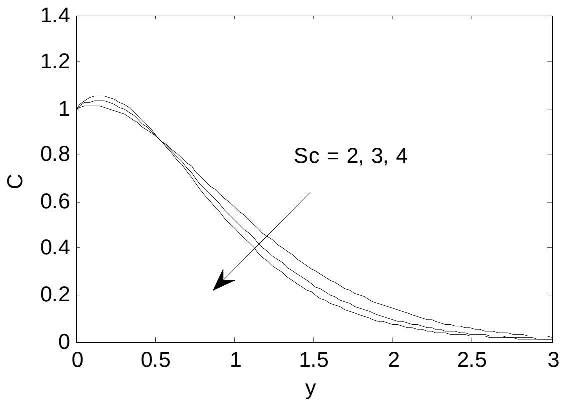

Figure 22: Concentration Distribution for Various Values of Sc

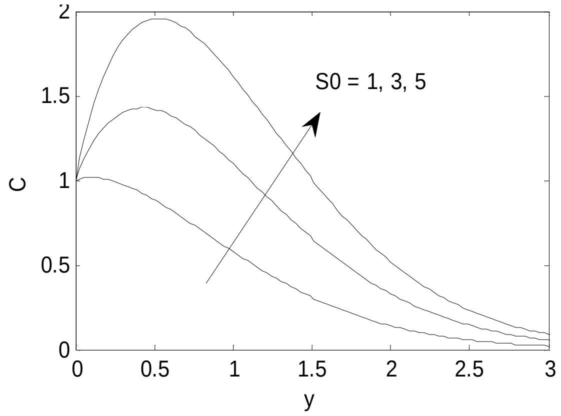

Figure 23: Concentration Distribution for Various Values of So

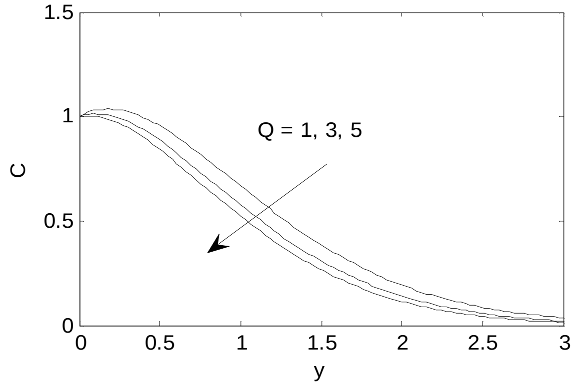

Figure 24: Concentration Distribution for vgarious values of Q

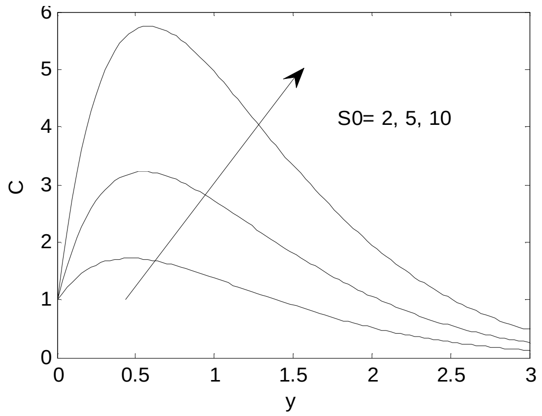

Figure 25: Concentration Distribution for various Values of So (pr=1, sc=1)

Table 1: Skin Friction (for Pr ≠ 1 & Sc ≠ 1)

Pr	F	Sc	S0	M	Gr	Gm	Q	α	m	Sf
0.71	2.00	2.00	1.00	2.00	2.00	2.00	3.00	0.52	0.50	717.04
0.90	2.00	2.00	1.00	2.00	2.00	2.00	3.00	0.52	0.50	75069.91
0.71	**5.00**	2.00	1.00	2.00	2.00	2.00	3.00	0.52	0.50	34181.88
0.71	2.00	**3.00**	1.00	2.00	2.00	2.00	3.00	0.52	0.50	285.01
0.71	2.00	2.00	**1.50**	2.00	2.00	2.00	3.00	0.52	0.50	1027.15
0.71	2.00	2.00	1.00	**2.50**	2.00	2.00	3.00	0.52	0.50	-194.66
0.71	2.00	2.00	1.00	2.00	**3.00**	2.00	3.00	0.52	0.50	778.03
0.71	2.00	2.00	1.00	2.00	2.00	**3.00**	3.00	0.52	0.50	1027.39
0.71	2.00	2.00	1.00	2.00	2.00	2.00	**5.00**	0.52	0.50	6409.70
0.71	2.00	2.00	1.00	2.00	2.00	2.00	3.00	**0.79**	0.50	594.77
0.71	2.00	2.00	1.00	2.00	2.00	2.00	3.00	0.52	**1.00**	898.51

Table 2: Skin Friction (for Pr = 1 & Sc= 1)

F	S0	M	Gr	Gm	Q	α	m	Sf
2.00	1.00	2.00	2.00	2.00	3.00	0.52	0.50	11.12
5.00	1.00	2.00	2.00	2.00	3.00	0.52	0.50	11.15
2.00	**1.50**	2.00	2.00	2.00	3.00	0.52	0.50	11.93
2.00	1.00	**2.50**	2.00	2.00	3.00	0.52	0.50	12.12
2.00	1.00	2.00	**3.00**	2.00	3.00	0.52	0.50	14.47
2.00	1.00	2.00	2.00	**3.00**	3.00	0.52	0.50	11.60
2.00	1.00	2.00	2.00	2.00	**5.00**	0.52	0.50	11.03
2.00	1.00	2.00	2.00	2.00	3.00	**0.79**	0.50	9.72
2.00	1.00	2.00	2.00	2.00	3.00	0.52	**1.00**	9.82

Table 3: Nusselt Number (for Pr ≠1)

Pr	F	Q	Nu
0.71	2.0	3.00	3.76
0.9	2.0	3.00	4.23
0.71	**5.0**	3.00	4.77
0.71	2.0	**5.00**	4.46

Table 4: Nusselt Number (for Pr = 1)

F	Q	Nu
2.0	3.00	4.46
5.0	3.00	5.66
2.0	**5.00**	5.29

Table 5: Sherwood Number (for P≠1 & Sc≠1)

Pr	F	Sc	S0	Q	Sh
0.71	2.0	2.0	1.00	3.00	77.61
0.9	2.0	2.0	1.00	3.00	310.27
0.71	**5.0**	2.0	1.00	3.00	441.65
0.71	2.0	**3.0**	1.00	3.00	35.77
0.71	2.0	2.0	**1.50**	3.00	113.71
0.71	2.0	2.0	1.00	**5.00**	186.52

Table 6: Sherwood Number (for P=1 & Sc=1)

F	S0	Q	Sh
2.0	1.00	3.00	3.42
5.0	1.00	3.00	4.04
2.0	**1.50**	3.00	4.82
2.0	1.00	**5.00**	3.85

5 CONCLUSIONS

In this study, a general analytical solution for the problem of Hall current and Radiation effects on MHD free convective Heat and Mass transfer flow past an accelerated inclined porous plate with Thermal diffusion have been determined using Laplace transform technique. The expressions for Velocity, temperature, concentration, Skin friction, the rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number have been derived and discussed through graphs and tables. From the study the following conclusions can be drawn:

- The velocity profile increases with increase in Pr, Gr, Gm, Q, F, So, and M while it decreases with increase in Sc, m and α (for Pr≠1 and Sc≠1).
- The velocity profile increases as Gr, Gm, F, m increase respectively while it decreases as M and α increase. (for Pr=1 and Sc=1)
- The temperature decreases with increase in values of Pr and F (for Pr≠1).
- The temperature decreases with increase in values of Q (for Pr=1).
- The Concentration increases with increase in F and So, while it decreases with increase in Sc and Q (for Pr≠1 and Sc≠1).
- The Concentration increases with increase in So (for Pr=1 and Sc=1).
- Velocity on skin friction increases with increase in Pr, Gr, Gm, So, F, Q and m, while it decreases with increase in Sc, M and α (for Pr≠1 and Sc≠1).
- Velocity on skin friction increases with increase in Gm, Gr, M, F and So, while it decreases with increase in Q, m and α (for Pr=1 and Sc=1).
- The rate of heat transfer expressed in terms of Nusselt number increases with increase in Pr, F and Q.
- The rate of mass transfer expressed in terms of Sherwood number increases with increase in Pr, F, So and Q, while it decreases with increase in Sc.

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